TEST F2

HIGH ALTITUDE ELECTROMAGNETIC PULSE

F2.1 PURPOSE This is a laboratory test which determines fuze ability to satisfy safety and reliability requirements when exposed to a simulated high-altitude electromagnetic pulse (HEMP) environment. This HEMP potentially could initiate or alter electro-explosive devices (EEDs) and destroy or damage vulnerable electronic components in the fuze.

F2.2 DESCRIPTION

F2.2.1 General. This test is intended to evaluate fuzes in their storage, transportation and handling configurations. Testing of fuzes with munitions in their tactical configurations is discussed under Section F2.6. Fuzes shall be subjected to one of the simulated electromagnetic pulse environments described below. Where the test capability is available, the classified HEMP environment shall be utilized. These environments are applicable to altitudes less than 20,000 meters.

F2.2.1.1 Unclassified HEMP. The unclassified HEMP (see F2.7.6.1) is defined as:

$$E(t) = 5.25 \times 10^{4}(e^{-4\times10^{6}t} - e^{4.76\times10^{8}t})$$

and

$$H(t) = E(t) \div z$$

where

t is time in seconds;
z = 377 ohms, the characteristic impedance of free space;
E is the electric field in volts/meter; and
H is the magnetic field in amperes/meter.

The above equation has a pulse wave shape with time, with a peak field strength (Ep) of 50 kilovolts per meter, a 10 to 90 percent rise time of 4.15 nanoseconds, a time to half-value of 185.5 nanoseconds and a time duration between .1 Ep values of 587.8 nanoseconds. The Electric Field Spectrum and Normalized Cumulative Energy Density Spectrum are presented in Figure F2-1 (see F2.7.5.2). The minimum requirements for the simulation of this waveform for the purpose of this test are presented in F2.4.1.3.

F2.2.1.2 Classified HEMP. The secret HEMP environment is defined in DOD-STD-2169A.

F2.2.2 Fuze configuration. The fuze shall be completely assembled, including all electronic circuits and electroexplosive devices that are a part of the fuze design. Lead and booster charges may be omitted to facilitate testing, if considered insenitive or inaccessable to HEMP, or substituted with appropriate inert explosive component simulant provided that the electromagnetic configuration of the munition is maintained. If the fuze is normally shipped or stored on a munition, then the test shall be conducted with the fuze assembled in an inert test munition that provides the same electromagnetic characteristics, such as conductivity, shielding, internal and external wiring of the operational munition. If the fuze is used in multiple munitions, the test shall be conducted in each munition or the munition in which the fuze is considered to be the most susceptible to HEMP. If the fuze is not normally installed in a munition for shipping or storage, then the fuze in its standard packaged configuration shall be tested. If the fuze is normally shipped or stored unpackaged, it shall be tested in the unpackaged configuration. The fuze configurations chosen for the test shall be based on all known transportation, storage and handling configurations and the susceptibility analyses as described in F2.2.5.1 of this test; see also F2.7.4.3.

F2.2.3 Applicable publications. All standards, specifications, procedures and manuals which form a part of this test are listed in Section 2 of this standard.

F2.2.4 Number of test items

a. If the item is to be instrumented, a single test item is sufficient for each individual test sequence (i.e., operational mode, test configuration and orientation).

b. If the item is not to be instrumented, a minimum of 10 items is required for each individual test. Each individual test will include exposure to at least 10 HEMP pulses. For tests where 10 items are not available, see F2.3.2.2.

F2.2.5 Documentation. Test plans, performance records, equipment, conditions, results, and analyses shall be documented in accordance with section 4.8 of the general requirements of this standard. The following unique requirements also apply.

F2.2.5.1 Analyses. The HEMP coupling analyses shall be conducted for all known transportation, storage and handling configurations for the fuze. The analyses should determine and provide the most significant system configurations, test configurations and orientations; whether the fuze is to be instrumented for test; the determination of the parameters to be monitored; the expected stress levels; the component thresholds for upset and permanent damage; prioritization of likely failure modes and rationale for the components to be instrumented; etc..

F2.2.5.2 Test plan. The formulation of an appropriate test plan shall be based on the analyses of F2.2.5.1. The test plan shall include:

a. Identification of the fuze items to be tested at the applicable level of component integration (i. e., system, munition, fuze, subsystem, assembly, circuit, individual component, etc.), and the following pertinent data and information:

(1) The tests and parameters to be measured before, during and after the HEMP environment is applied. The test record data sheet format shall be included.

(2) The test points and supporting rationale for choices.

(3) Instrumentation employed for the response measurements.

(4) Ambient conditions.

(5) Functional modes to be evaluated and supporting rationale for choices.

(6) Number of test items and controls:

a. See F2.2.4 and F2.3.2.2.

b. The time between pulses shall be greater than 5 times the thermal time constant of the components of concern.

(7) Physical configuration of the test items and any ancillery equipment when exposed to the test environment, and the number of test items for each configuration, operational mode and orientation.

(8) The number and kinds of spare parts required.

(9) The data to be recorded.

(10) The specified HEMP free field test waveforms and frequency spectra.

(11) The method of operation and monitoring of the equipment.

b. A description of the test facilities to be employed to include instrumentation and simulator characteristics, environment measurement techniques, and calibration procedures. Also the justification for choosing the simulator or simulation techniques, including the pertinent simulator characteristics needed.

c. A description of how the chosen simulator environments resemble and differ from the threat environment and the methodology for extrapolating the test results to those that would result by exposing the system to the threat environment.

d. A statement of the specific test levels and test sequences and the survivability requirements to be assigned to each test.

e. The controls to protect personnel and equipment in event the fuze functions during test.

F2.2.5.3 Test report. The test report shall contain the test plan, all the data and the conclusions resulting from the tests delineated in the test plan. In particular the test report shall provide:

a. The transient responses of the sensor outputs, starting with time zero, as well as that of the simulated HEMP field.

b. A statement of how the simulated environments were measured; where with respect to the sample the measurements were made; and what device or instruments were used.

c. A detailed description of the instrumentation calibration procedures.

d. A description of the operational steps used to set up the fuze for tests.

e. A description of how the actual test procedure differed from the test plan.

f. Details of the fuze post-exposure status.

g. A detailed description of how the response information on components, subassemblies and assemblies is analyzed to arrive at an evaluation of the system survivability. This analysis should relate measured data to the components' failure levels.

h. A statement of whether the fuze has met the criteria for passing the test (Section F2.3) and the rationale for this conclusion including assumptions and engineering judgments made to support the conclusions.

F2.3 CRITERIA FOR PASSING TEST

F2.3.1 Fuze condition. At the completion of this test, the fuze shall be safe for transportation, storage, handling and use, as well as operable in accordance with Paragraphs 4.6.2.1 and 4.6.2.2a of the general requirements to this standard. The fuze shall perform in accordance with its performance specifications.

F2.3.2 Decision basis. Breakdown, inspection, other appropriate tests and engineering judgment shall form the basis for the decision that fuzes have passed or failed the test.

F2.3.2.1 Instrumented fuzes. For electroexplosive devices, the maximum pin-to-pin and pin-to-case no-fire criteria establish the baseline. For electronic components, threshold damage data based on actual tests or analyses may be used; in their absence, Wunsch damage criteria apply. See references F2.7.6.3 and F2.7.6.4. For all components for which a failure represents a safety hazard, a 20-dB safety factor shall be applied to induced power, energy, voltage and/or current,depending on the damage characteristics of the component. For all other components, a 10 dB safety factor shall be applied.

F2.3.2.2 Non-instrumented fuzes. For tests that have used at least 10 items exposed 10 times for each individual test, a test stimulus amplitude of at least threat level is required. For tests that have used less than 10 items, but at least two, a test stimulus amplitude of at least 6dB above threat level is required.

F2.4. EQUIPMENT

F2.4.1 HEMP simulator. A HEMP simulator such as operated by the Army, Navy or Air Force may be used. The services have used bounded wave simulators as shown in Figure F2-2, large enough to accommodate a large airplane and others small enough to sit on a laboratory work bench. Other simulators meeting the specifications below may also be used. (see F2.7.3).

F2.4.1.1 Field intensity uniformity. With the test munition outside the test area, the field intensity in the test area shall be measured at 6 equally spaced points on the surface that would be generated by rotating the test munition about its center in all directions; the center of rotation will be at the center of the test area. The position of test points shall insure that only one line connected between opposite points will be parallel to the E-field. The field intensities measured on the surface shall not differ by more than 10% from those measured at the center of rotation.

F2.4.1.2 Field intensity loading. To ensure that the test munition does not excessively load the test fields, a dipole cut to the largest dimension of the test munition shall be placed in the center of the test area, parallel to the E-field. Two more identical dipoles are to be placed in the center of the test area so that all three are mutually orthogonal. The current induced in the center of the dipole parallel to the E-field shall be 100 +/- 10% of the current induced by a prior to loading equal intensity radiated plane wave in space. For a bounded wave simulator, this requires that the ratio of the largest dimension of the test munition to the plates' separation distance be .6 or less.

F2.4.1.3 Unclassified HEMP. The equipment shall provide HEMP fields as specified in Figure F2-3 with a risetime of 10 ns or less, a fall time greater than 100 ns and a peak aplitude of at least 50 kV/m.

F2.4.1.4 Secret HEMP. The equipment shall provide HEMP fields as specified in D0D-STD-2169A.

F2.4.2 Fuze instrumentation. The fuze may be instrumented to measure induced currents and/or voltages at the critical circuit locations determined by the analyses of F2.2.5.1. For EEDs, both pin-to-pin currents and pin-to-case voltages shall be monitored. Fuze instrumentation shall not excessively distort the incident field, induce spurious signals in the fuze or alter the data. This may be accomplished with fiber optics or microwaves to transmit data between the fuze under test and the remotely positioned recording instrumentation. Alternately, data can be brought out via well-shielded coaxial lines with connectors in the fuze skin. The lines should be routed perpendicular to the E-field using appropriate RF-absorbant material to minimize electromagnetic coupling. Tests should be performed to insure there are no instrumentation-induced errors.

F2.5 PROCEDURE

The fuze in its most vulnerable configurations, as described in F2.2.2, shall be exposed to the simulated HEMP. For all test configurations, the fuze shall be so oriented with reference to the incident E-field and H-field as to ensure maximum coupling of energy to all components of concern. If maximum coupling to different components requires different orientations, or if worst case coupling cannot be determined a priori, various orientations shall be used to assure testing in the worst case conditions.

F2.5.1 Test arrangements. The arrangement that gives maximum coupling shall be used if known; otherwise, both of the following arrangements shall be used.

F2.5.1.1 Monopole. The fuze under test shall be supported by a dielectric structure. One end of the munition shall be grounded, thereby simulating a monopole antenna. The major axis of this arrangement shall be oriented parallel to the electric field.

F2.5.1.2 Dipole. The fuze under test shall be supported by a dielectric structure and isolated from ground, thereby simulating a dipole antenna. The major axis of this arrangement shall be oriented parallel to the electric field.

F2.5.2 Compliance. The fuze shall be tested according to the test plan and the results analyzed to determine whether the fuze meets the pass/fall criteria in Section F2.3.

F2.6 ALTERNATE AND OPTIONAL TESTS

For those instances where the fuze developer must evaluate the fuze vulnerability to HEMP under tactical conditions, tests shall be performed with the fuzes and munitions in their launch preparation, launch, and flight configurations as applicable. All fuze modifications, instrumentation, analyses, and documentation requirements are identical to those for tests performed in the transportation, storage and handling configurations.

F2.7 RELATED INFORMATION

F2.7.1 HEMP generation. A nuclear detonation creates an intense Electromagnetic Pulse (EMP) in addition to the shock, blast, ionizing radiation, and thermal effects. Although EMP is generated by surface, air, and high altitude nuclear bursts, it is the primary weapons effect of a high-altitude (exoatmospheric) burst and illuminates the largest area on the earth' s surface, thousands of square miles. In addition, at distances great enough for the other effects to become small, the high-altitude burst generates the most severe EMP (HEMP) threat. For a high-altitude nuclear burst occurring at altitudes above 40 km, gamma rays collide with air molecules (Compton collisions), causing electrons to be ejected. These Compton recoil electrons spiral under the influence of the earth's magnetic (geomagnetic) field. Spiraling causes them to accelerate, and hence radiate, thereby producing the electromagnetic pulse.

F2.7.2 HEMP Characteristics

F2.7.2.1 Origin of the unclassified HEMP. High-altitude EMP develops significant field strength over a wide area of coverage. However, its amplitude-time history and polarization are not uniform over this area, and depend primarily on the orientation of the geomagnetic field and the observer's location in comparison to the burst. A double exponential generalized wave shape, independent of observer location, has been developed by the EMP community, and is used as a working characterization (see F2.2.1.1.a and Figure F2-3). This constructed wave form represents a composite of extremes that occur in different regions within the area of coverage, combining the shortest rise time, maximum peak amplitude and longest fall time. Because of the geomagnetic dip angle, over the United States, the HEMP is primarily horizontally polarized with a peak electric field amplitude of 50,000 v/m, with a vertical component of 15,000 v/m. This represents the incident fields. The total fields at any point also include reflection of these fields from the ground plane. The total fields can be larger or smaller than the incident fields, depending on polarization, These characteristics are the basis of worst case evaluation of HEMP interaction with fuzes.

F2.7.2.2 Comparison with other EM fields. HEMP is similar to the radiated electromagnetic pulse produced by a lightning stroke. However, it has a faster rise time and illuminates a much larger area with an intense field. The HEMP electric field intensity rises to levels as high 50kv/m in less than ten nanoseconds, and then decays to an insignificant value in less than 1.0 microsecond. Although this time span is very short, the pulse amplitude is much larger than ordinary radio signals. When HEMP is coupled into an object, the object "rings" at one or more resonant frequencies. The current or voltage wave forms induced are thus usually a superposition of damped sinusoids. The ability of HEMP to couple energy to an object often depends strongly on its spectral amplitude at these resonances. In addition to direct excitation of system elements, HEMP energy can be transferred to a munition system by the interconnecting cables which act as receiving antennas and transmission lines.

F2.7.3 Simulation techniques.

F2.7.3.1 Use of HEMP simulators. It is not feasible to explode a nuclear bomb whenever the need to assess the susceptibility of a weapon to HEMP arises. Hence HEMP simulators have been developed to simulate the HEMP environment. As with most environmental simulators, each HEMP simulator has particular strengths and weaknesses with regard to simulating the actual HEMP, depending on the test conditions and the weapon to be tested. Extensive knowledge about the system to be tested and effects to be examined are necessary for selecting a HEMP simulator.

F2.7.3.2 Types of HEMP simulators. Many kinds of HEMP simulators have been developed and are in the process of being developed. Simulation test techniques are similarly in their evolutionary phases. Recent concerns of the Environmental Protection Agency (EPA) about HEMP simulators polluting the environment with their fields has stimulated interest in those which have minimum radiated fields. Also, simulators that cost less to purchase, operate and maintain have become more widely used, adding to their consideration for use as a standard. The equipment and techniques given below are discussed in greater detail in references F2.7.6.5 and F2.7.6.6.

F2.7.3.2.1 Pulse radiation simulators. Biconic Dipole and Resistive Loaded Horizontal Dipole (both horizontally polarized), and Inverted Conical Monopole (vertically polarized) are all classified as pulse radiation simulators. The intensity of the useful test fields that can be radiated by these devices is limited because of the following factors:

a. Test field intensity falls off inversely with distance.

b. Test object must be positioned a sufficient distance from the antenna to assure far-field conditions.

c. Maximum field intensity that can be generated is limited by the state-of-the-art in the design and manufacture of high voltage generators and switches and by their high cost to purchase and maintain.

d. Field intensity uniformity cannot be maintained across large systems.

F2.7.3.2.2 Bounded wave transmission line simulators. These simulators can be used to establish plane waves within the two plates of a transmission line as depicted in Figure F2-2; this provides vertically polarized fields. Another type makes use of two vertically positioned plates positioned above ground, thereby, providing balanced lines. This type is horizontally polarized and has the advantage of minimum radiated fields, with the external fields at a distance 100 feet from the chamber being down more than 60 dB from those inside the chamber. A third type, called the Crawford cell, was developed by W. Crawford, National Institute of Standards and Technology. This has a three-dimensional shape similar to the parallel plate lines, except it is a coaxial system enclosed on all sides. This cell has the advantage of radiating even less than the balanced line, but for a given size has less test area available. Because the energy delivered to these transmission lines is more confined than from radiating antennas, the same intensity energy source can establish much higher intensity fields. Where the plates are closer together, the fields can be proportionately higher. It is possible to design a chamber to provide the choice of a 377 ohm field, a low impedance field or a high impedance field. This allows simulation of a reflected field that adds or subtracts from' the E-field component. These chambers can be used to establish either HEMP fields or CW fields. The maximum HEMP field available from an existing chamber is 125 kv/m; in this case the separation distance between plates is 40 feet. Moving the plates closer increases field intensity; increased field intensity for smaller objects can be obtained in the transition section of this chamber.

F2.7.3.3 Low intensity test fields. Low intensity test fields can be useful in the developmental stage of an item to evaluate weaknesses in the system and to aid in design. However, it is not possible to extrapolate low intensity field effects up to threat levels because of weapon component non-linearities at those levels. Final evaluation of the system is necessary at threat level fields or their equivalents.

F2.7.4 Reasons for HEMP concern. The increasing dependence of military operations on sensitive and sophisticated electronic equipment and the large-scale introduction of semi-conductor devices have significantly increased the possibility of collateral damage and degradation of mission performance due to HEMP. An area of particular concern is the HEMP vulnerability of ordnance. Potential exists for sufficient HEMP energy to be coupled to munitions to initiate EEDs. Fuzes having electronic safety and arming devices with in-line explosive trains are a more serious safety concern than those having conventional, interrupted explosive trains; for the latter, reliability is the primary concern. Furthermore, with the advent of smart weapons, much of the electronics, especially digital logic circuits responsible for propulsion control, arming, and fusing and guidance subsystems, are potentially susceptible to HEMP-induced damage or upset.

F2.7.4.1 EED initiation. In the case of ordnance containing sensitive EEDs, the HEMP energy could cause initiation. The initiation of EEDs could cause a safety hazard for ships, aircraft, weapon systems and personnel by directly functioning the fuze or its safety features or cause the dudding of ordnance. The mechanisms for initiation of the EED could include electrical breakdown through the explosive material between the pin and case as well as pin-to-pin current. Even when the heat generated by the single pulse of energy may be insufficient to initiate an EED, the EED may become permanently desensitized as a result of this thermal influence and fail to function properly at a later time. This latter case presents a reliability problem as the ordnance is effectively dudded.

F2.7.4.2 Electronic system damage or upset. Induced HEMP transients can produce two types of detrimental responses in electrical/electronic equipment: upset and permanent damage. Upset is the temporary generation of false signals that cause the system to take undesired actions. Damage refers to the degradation of a component to the point where it can not perform its design function. Both safety and reliability problems can result from either type of response.

F2.7.4.3 Other areas of concern. As subsystems are assembled into a complete operating system, their susceptibility to HEMP can change dramatically due to changes in effective shielding and size of the inadvertent antenna system exposed to HEMP. HEMP tests should, therefore, include evaluation of the vulnerability of the fuze in all of its significant system configurations. Where called for, tests should include munition operational environments before, during, and after launch.

F2.7.5 Test applicability.

a. The HEMP test is primarily a fuze test and need only be applied to those fuzes that contain electroexplosive devices or other electrical/electronic components. All fuzes should be safe and reliable following exposure to HEMP while they are in their storage and transportation configurations to ensure against a complete loss of capability of the stockpile in case of an HEMP event. If the fuze is also stored or transported while mounted on one or more munitions or outside its storage container, then these are appropriate test configurations. These tests will not evaluate electronic system upset, since this normally requires the electronic circuits to be activated, a condition that will not exist in transportation and storage configurations. All these tests are the responsibility of the fuze developer.

b. A statement, similar to a. above, can be made for the munition without fuze attached. Although these tests are normally the responsibility of the munition developers, test F2 may be used in the absence of a specific HEMP test for unfuzed munitions.

c. In general, for a munition, the conguration most susceptible to HEMP occurs during preparations for launch. At this time cables entering the munition, create antennas capable of capturing energy from electromagnetic fields. Also, the electronics and guidance system are activated. The second most susceptible configuration is the munition in flight, again because the electronics are activated, the fuze may be armed, and there may be an electrically conductive exhaust plume adding to the inadvertent antenna systems and increasing the chances for a fuze premature or malfunction. Not all munitions are required to be safe from HEMP under these conditions, because of practicality limitations.

d. For those munitions or weapon systems for which HEMP survivability is essential to mission success or platform safety, HEMP vulnerability tests are required. These tests should be conducted in all significant munition/weapon systems handling configurations to evaluate effects on EEDs, electronic system damage and upset on all components in the system, including those in the fuze. Test F2 does not necessarily apply to complete system tests and responsibility normally lies with the munition weapon developer.

F2.7.6 Bibliography.

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F2.7.6.1.2 DNA 2114H-2 (DDC AD 520943), Volume 2, Analysis and Testing, November 1971 (CONFIDENTIAL).

F2.7.6.1.3 DNA 2114H-3, Volume 3, Environment and Application, May 1972 (SECRET-RESTRICTED DATA).

F2.7.6.1.4 DNA 2114H-4 (DDC AD 522310), Volume 4, Resources, November 1971 (CONFIDENTIAL).

F2.7.6.2 EMP, Engineering and Design Principles by R. Sherman, R. A. DeMoss, W. C. Freeman, G. J. Greco, D. G. Larson, L. Levy, and D. 5. Wilson, Bell Telephone Laboratories, 1975.

F2.7.6.3 Semiconductor and Non-conductor Damage Study, by D. C. Wunsch and L. Marsitelli. Braddock, Dunn and McDonald (EMD) Final Report, Vol. 1, April 1969.

F2.7.6.4 Determination of Threshold Failure Levels of Semiconductor Diodes and Transistors Due to Pulse Voltage, by D. C. Wunsch and R. R. Bell, IEEE Transactions on Nuclear Science, Vol. NS-15, December 1968, pp 244-259.

F2.7.6.5 DNA 2772T (ADA058367) DNA EMP Awareness Course Notes, Third Edition, Oct 1977, by I. N. Mindel, IIT Research Institute.

F2.7.6.6 DNA-H-86-68V2 (Contract No. DNA 001-81-C-0252) DNA EMP Course Study Guide, Volume II, May 1986, (Restricted) by P. Dittmar, et. al., BDM Corporation.

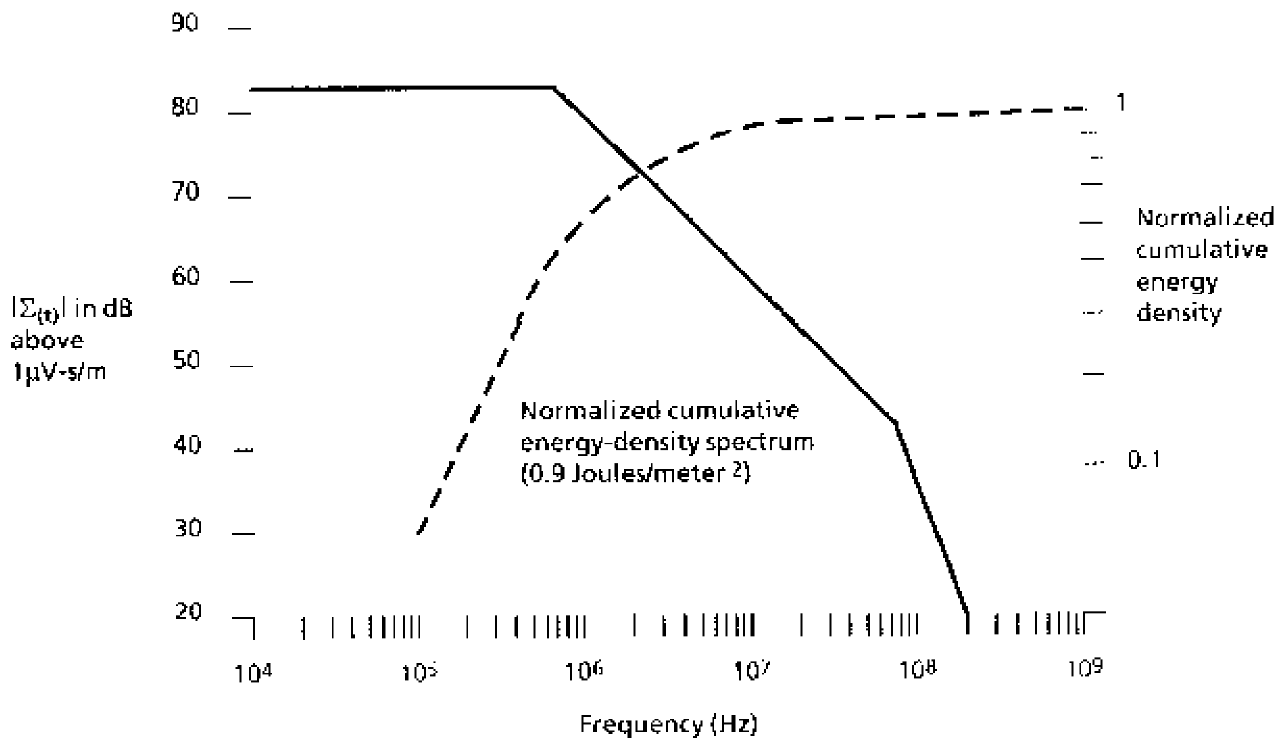

Figure F2-1. High-altitude EMP Spectrum and Normalized Energy Density Spectrum.

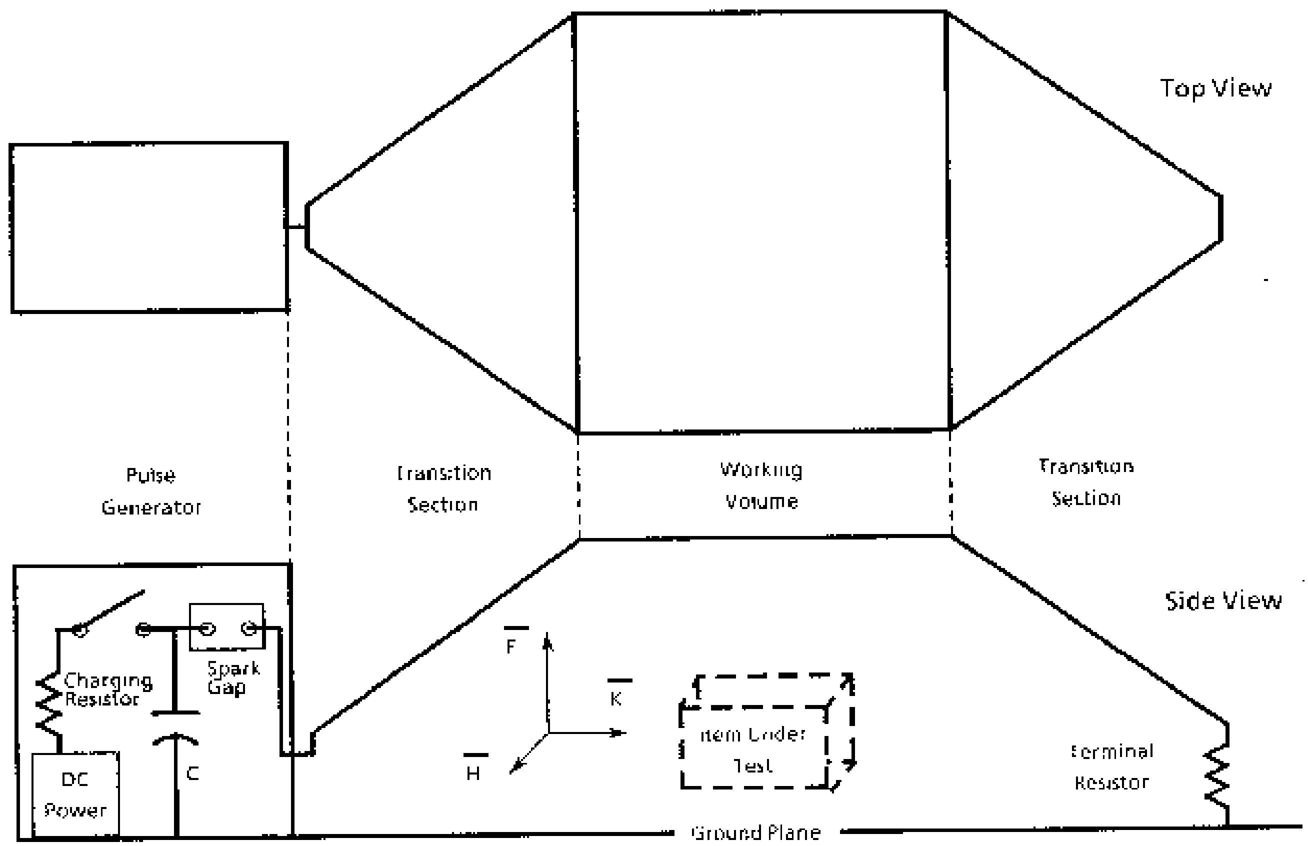

Figure F2-2. Bounded Wave Simulator.

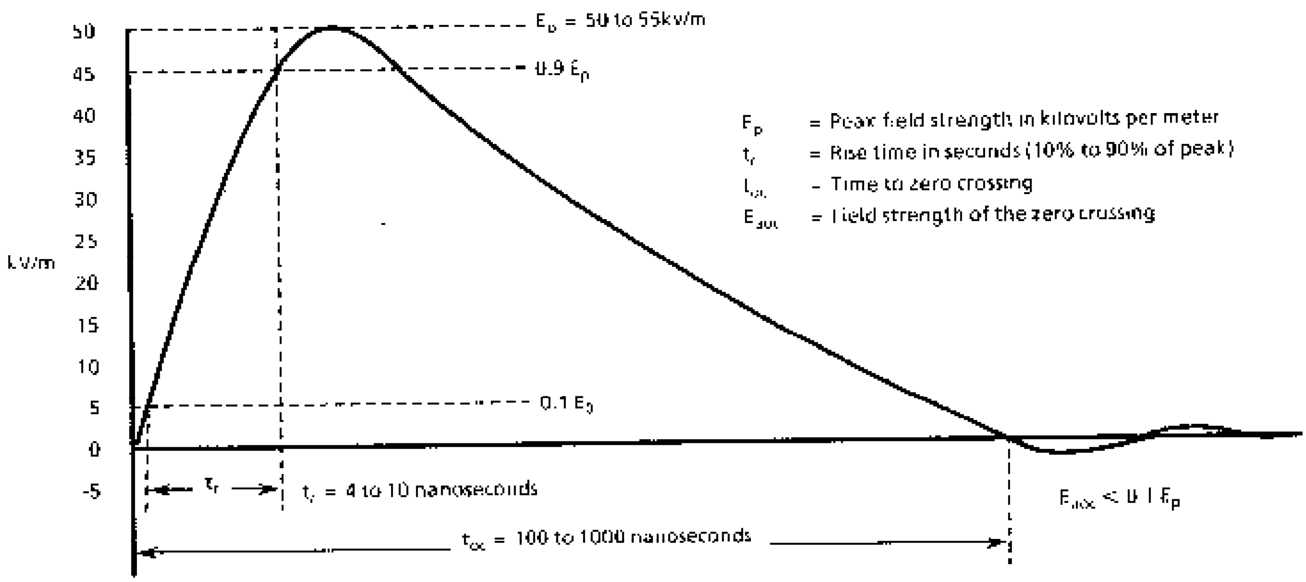

Figure F2-3. Characteristics of UNCLASSIFIED HEMP Simulator.